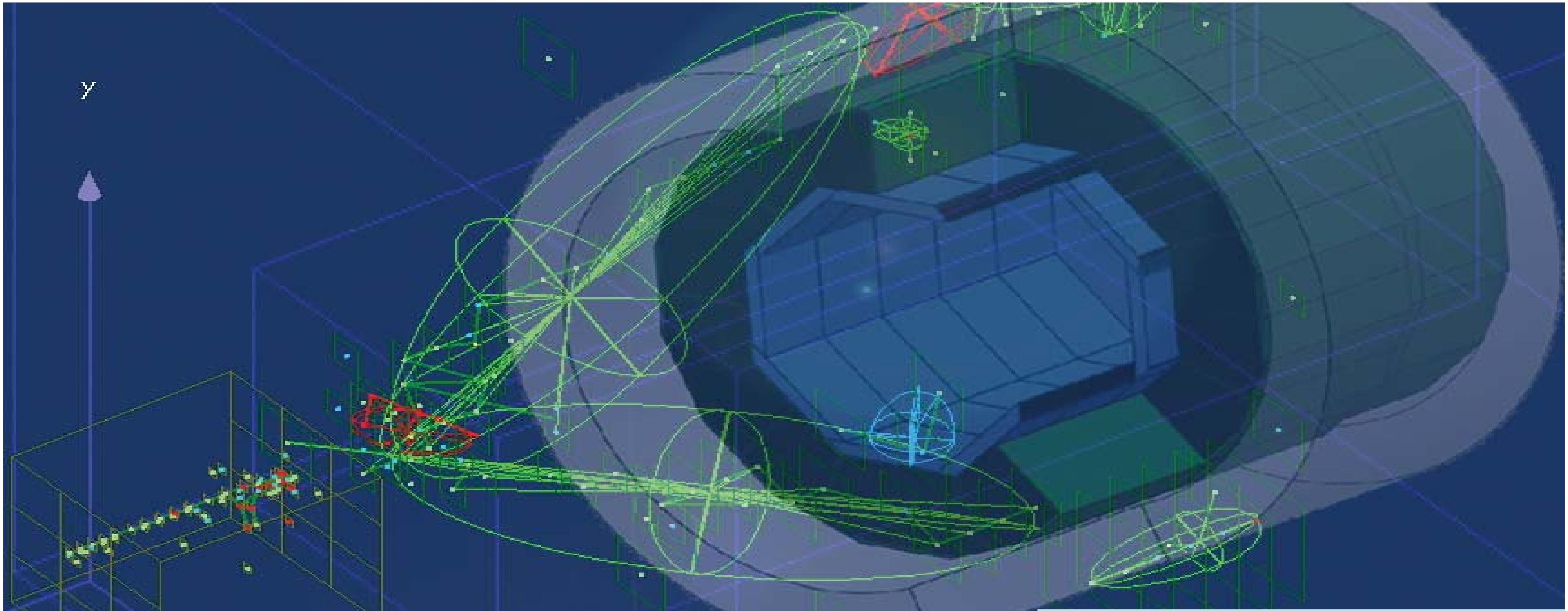
CALICE scintillator HCAL

Erika Garutti – DESY

(on behalf of the CALICE collaboration)

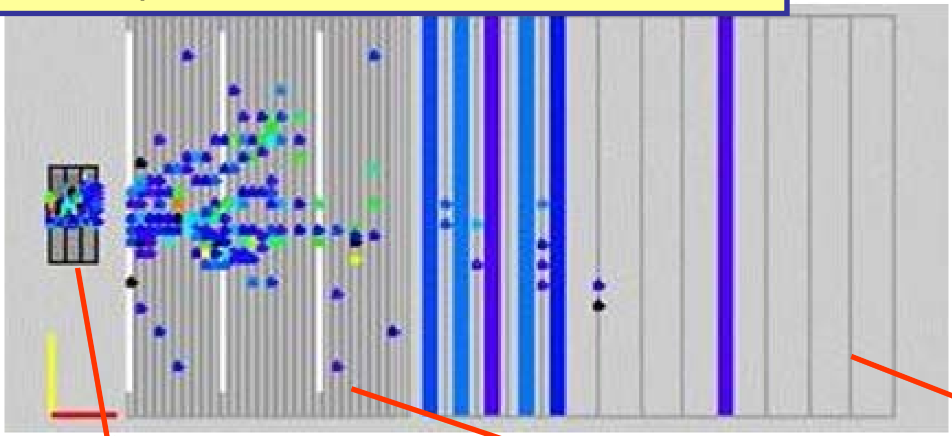


OUTLINE:

- electromagnetic and hadronic shower analysis
- shower separation

The test beam prototypes

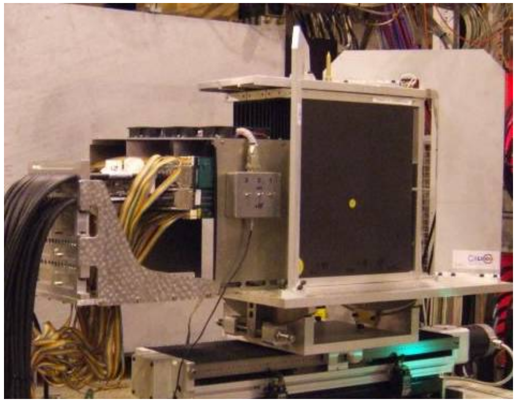
10 GeV pion shower @ CERN test beam



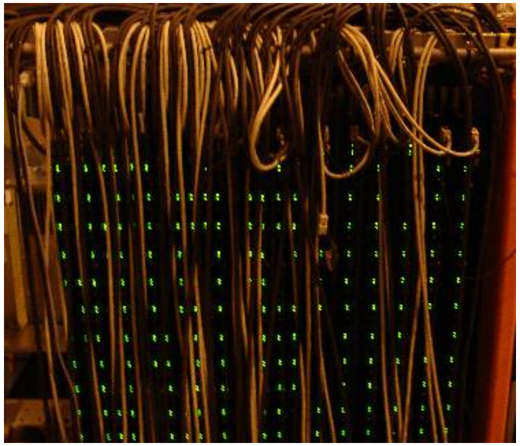
goal of prototype calorimeters:

- establish the technology
- collect hadronic showers data with unprecedented granularity to:
  - tune reco. algorithms
  - validate MC models

➔ see talk by Fabrizio Salvatore



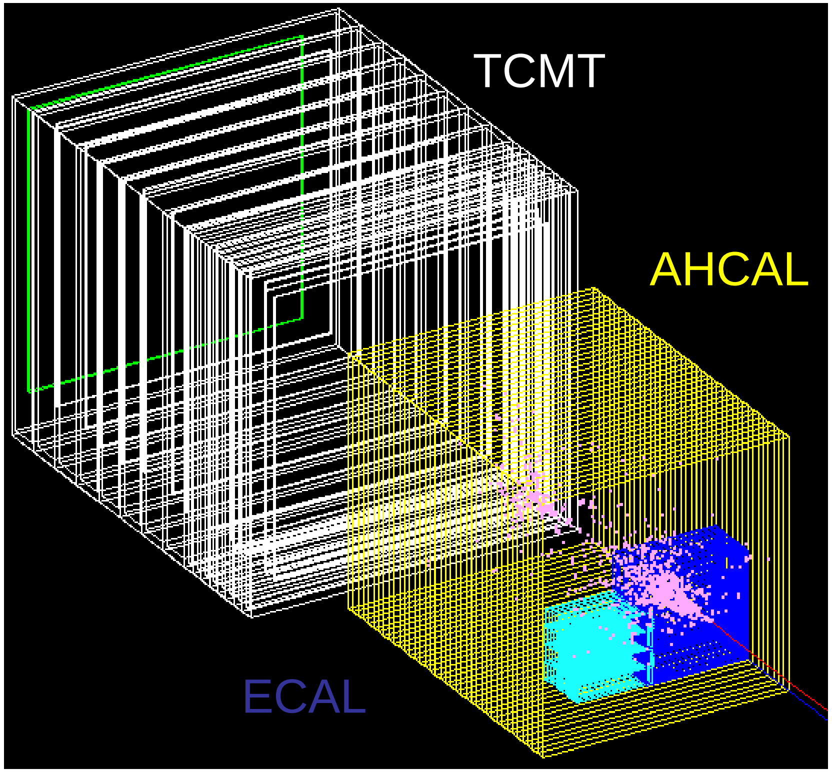
Si-W Electromagnetic calor.
1x1cm^2 lateral segmentation
1 X_0 longitudinal segment.
~10000 channels



Scint. Tiles-Fe hadronic calor.
3x3cm^2 lateral segmentation
~4.5 λ in 38 layers
~8000 channels

Scint. Strips-Fe Tail Catcher
& Muon Tracker
5x100cm^2 strips
~5 λ in 16 layer

Simulation



ECAL VFE electronics

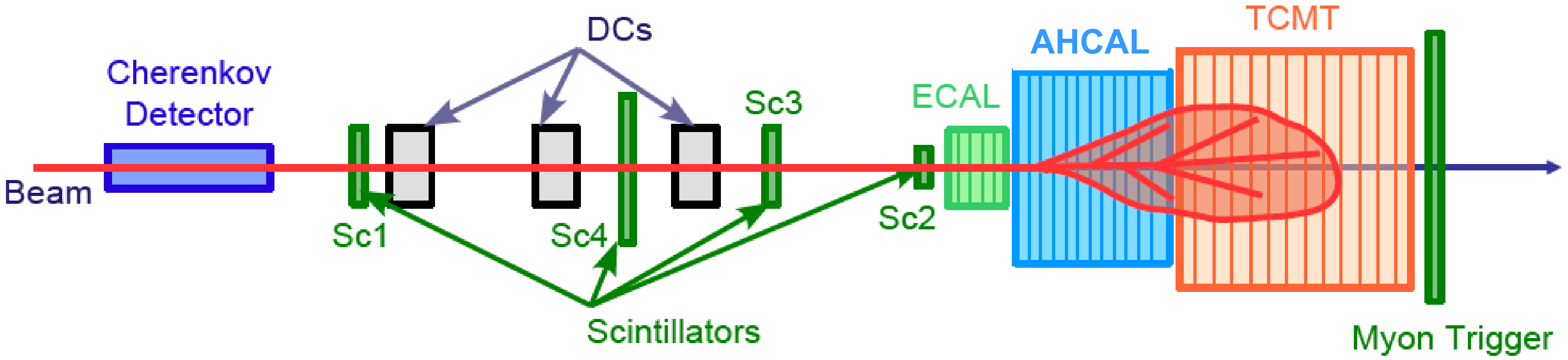
- GEANT4 used for all simulations
- various hadronic models tested

- geometry of all detectors and beam instrumentation implemented in MOKKA

- digitization applied to simulated events

specific for AHCAL:
-calibration to MIP scale
-non-linearity response of photo-detectors
-Poisson smearing (photo-detector stat.)
-addition of detector noise
-light crosstalk between calo. cells

Experimental set up



Analysis focus: AHCAL (+TCMT)

-electromagnetic showers without ECAL in place

-hadronic showers, use ECAL as tracker

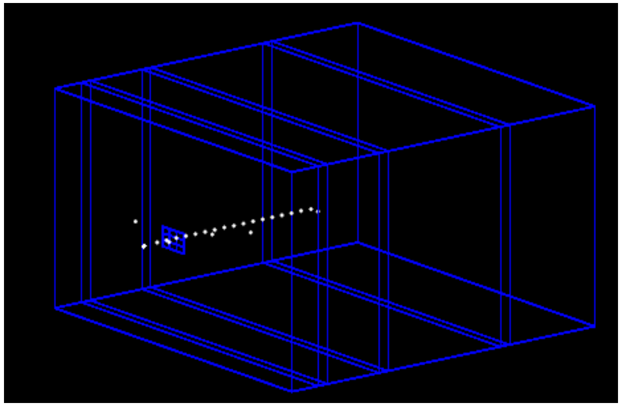
- contained in AHCAL ➔ impose cuts on TCMT E and number of hits
- non-contained ➔ sum AHCAL and TCMT energy (plus ECAL track E)

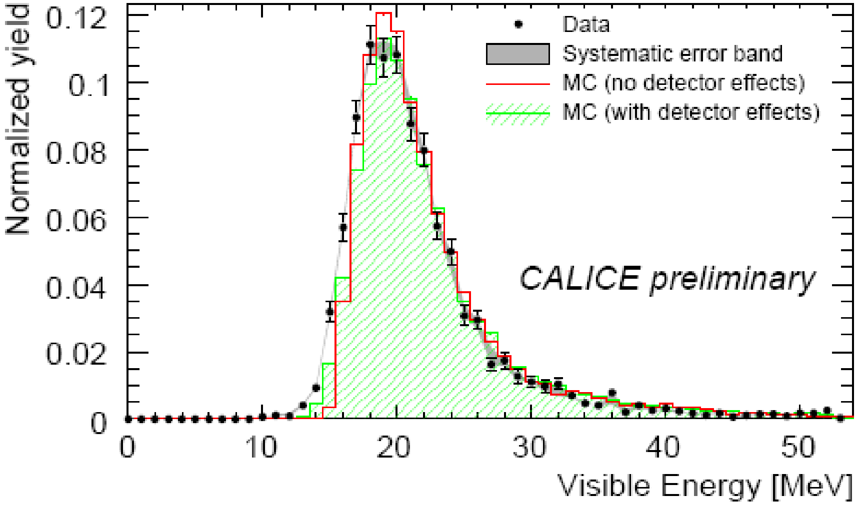
Simulation of muons

The calorimeter is calibrated at the MIP scale

➔ first check agreement data/MC for muon signal

➔ see talk by Angela Lucaci on Fri.



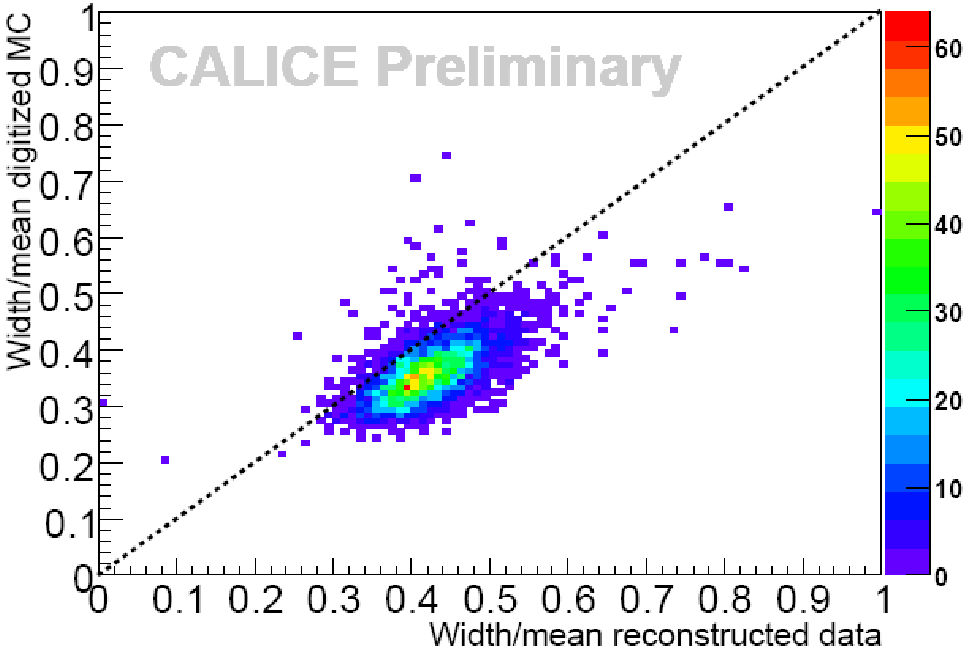


visible energy deposited by a muon in 23 calorimeter layers compared to true MC with and w/o digitization.

➔ agreement in amplitude and width of distribution

➔noise effects and smearing are less important than statistical smearing from physics when adding cells

Simulation of muons



MC + digitization:

width/mean of muon spectrum in each of the ~8000 cells of the AHCAL

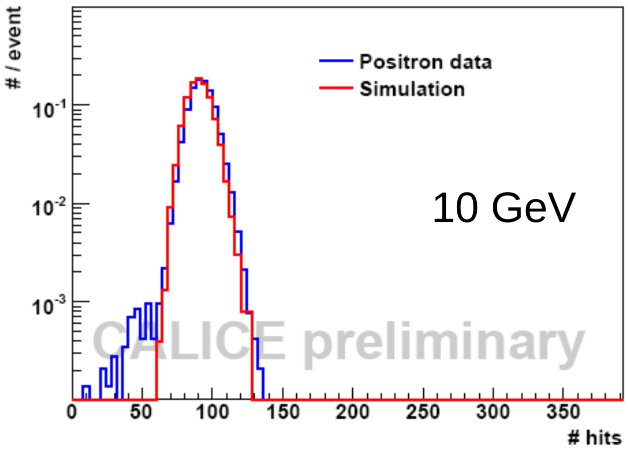
➔ good correlation data/MC

➔ MC width ~10% smaller than in data

not all effects included in MC yet e.g. tile non uniformity

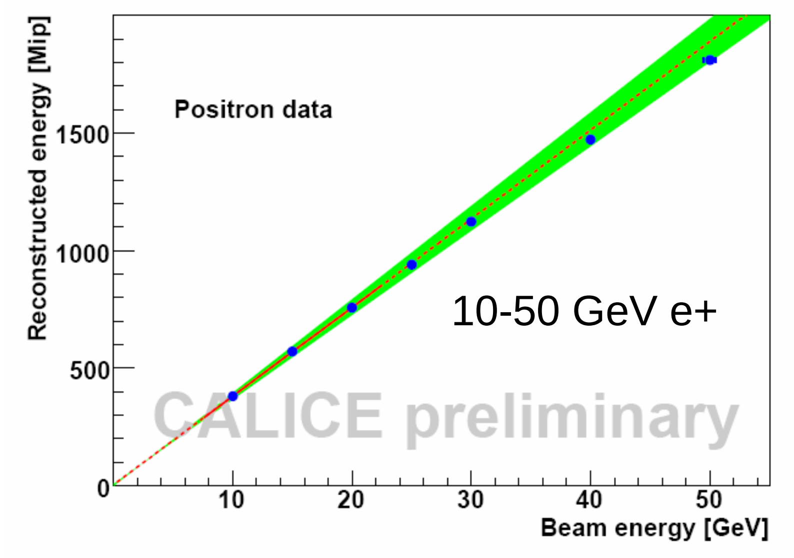
validation at the EM scale

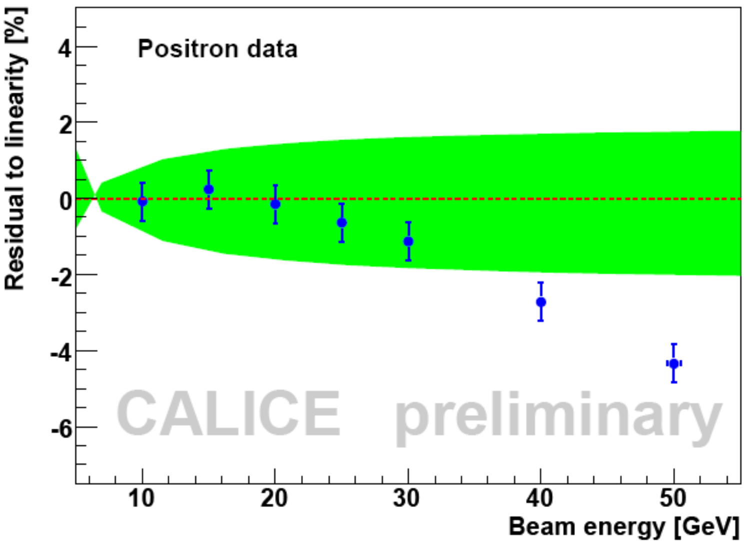
electromagnetic analysis needed to validate calibration procedure and MC digi



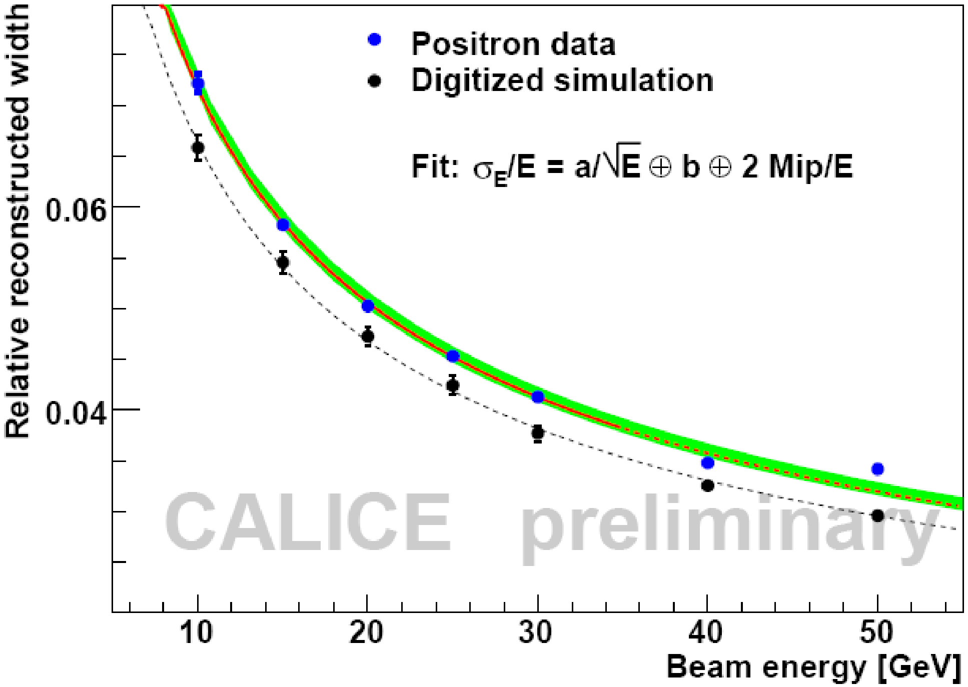
➔total number of hits about 0.5 MIP threshold
good agreement at low energy, max 5% diff at 50 GeV

linearity of calibrated calorimeter response:
~4% deviation at 50 GeV
systematic band from saturation scale uncertainty





Energy resolution



systematic band from saturation scale uncertainty

errors on energy scale cancel in ratio

noise term fixed from analysis of random trigger events = 2 MIP ~ 50MeV

stochastic term:

data: $22.6 \pm 0.1_{\mathrm{fit}} \pm 0.4_{\mathrm{calib}}\ \% / \sqrt{E}$

MC: $20.9 \pm 0.3_{\mathrm{fit}}\ \% / \sqrt{E}$

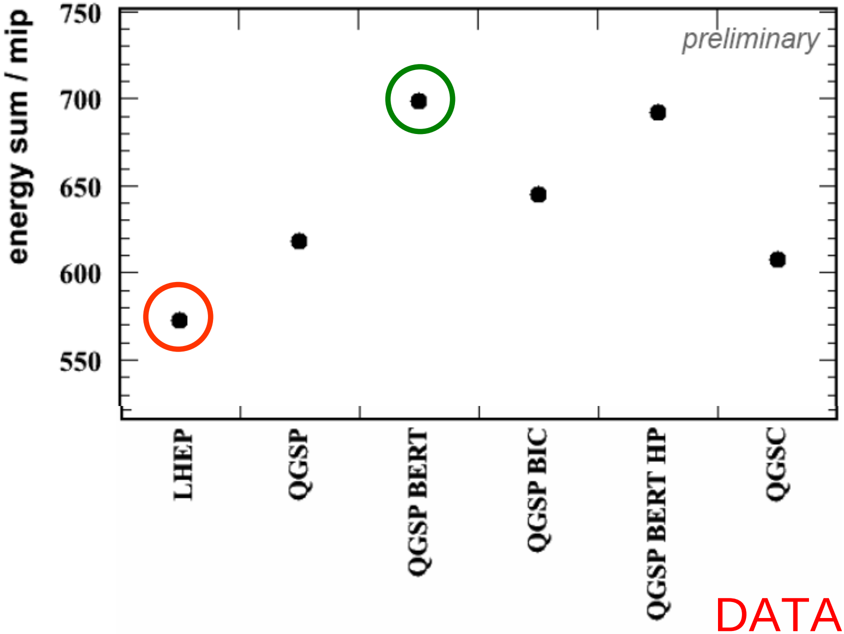
constant term:

data: $0 + 1.4_{\mathrm{fit}} + 0.3_{\mathrm{calib}}\ \%$

MC: $0 + 2.2_{\mathrm{fit}}\ \%$

Conclusion ➔ data/MC comparison on the EM scale satisfactory and sufficient for hadronic analysis. Remaining deviations smaller than 10%.

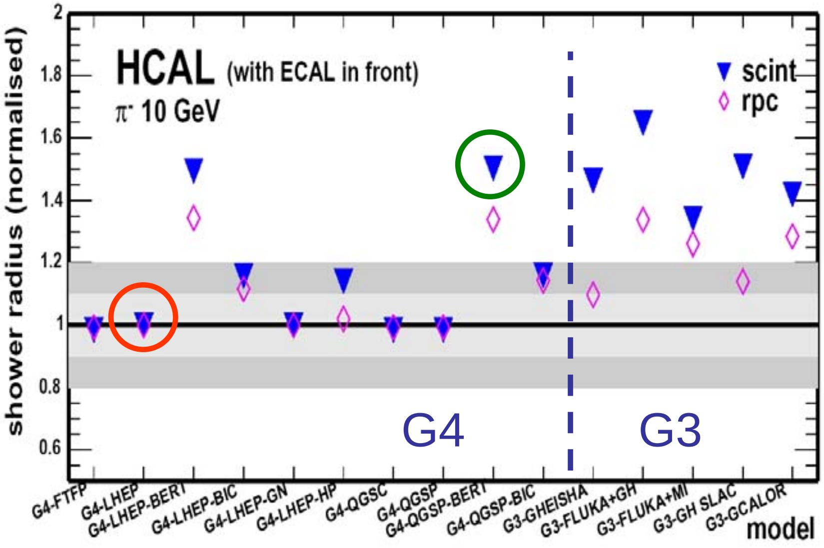
Validation of hadronic MC



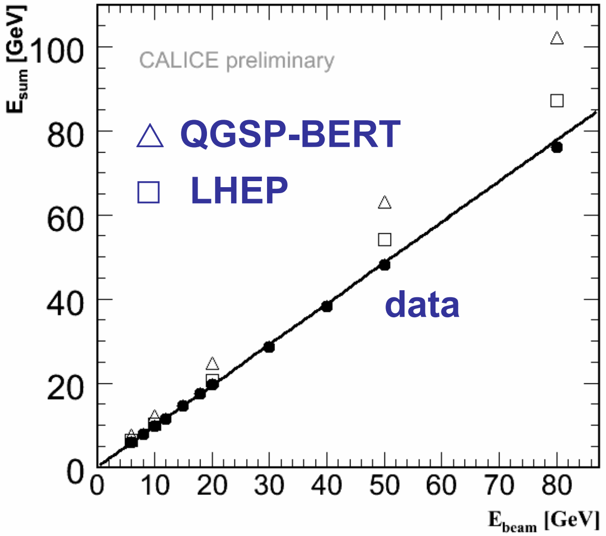
DATA?

The high granularity of the CALICE prototypes offers the possibility to investigate longitudinal and lateral shower shapes with unprecedented precision

large variation between available hadronic MC models



AHCAL: Response to hadrons

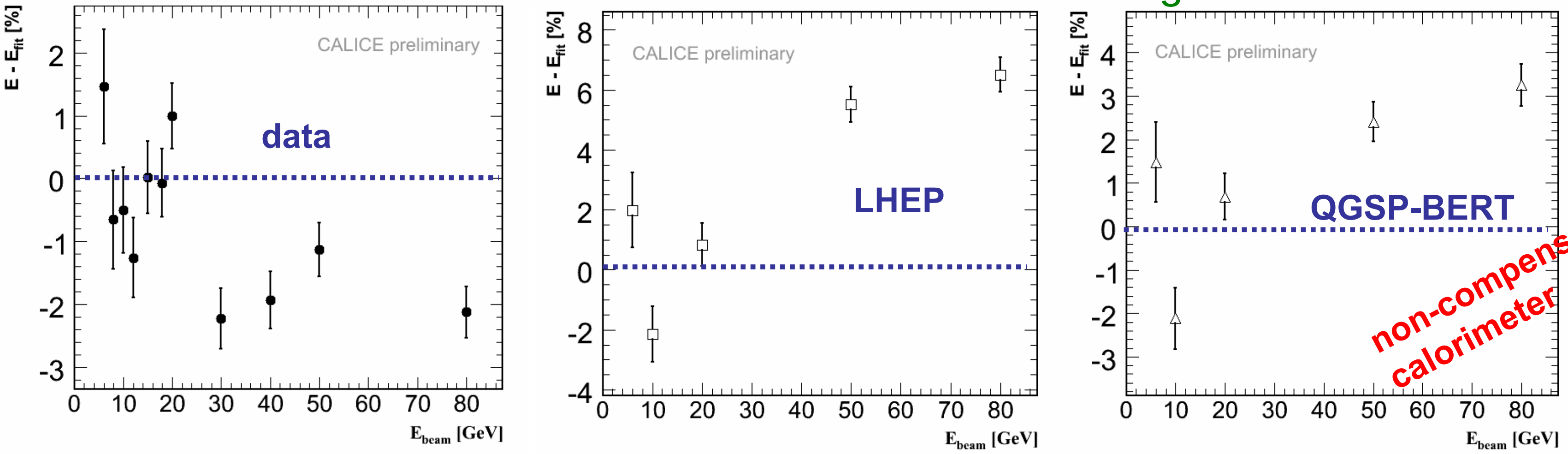


MC + digi with same sampling factor and MIP/GeV conversion as data

difference in absolute scale:
LHEP ~4%, QGSP_BERT ~20% larger than data

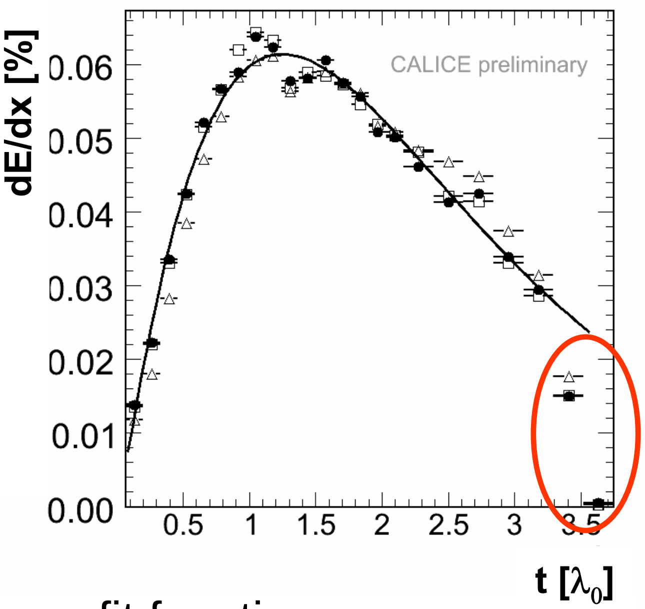
difference in linearity behavior
residual detector systematic to be quantified

residuals to linear fit in the range 6-20 GeV



non-compensating calorimeter

longitudinal shower profile



- no containment cut imposed on AHCAL
- no correction for shower starting point

➔ QGSP_BERT later shower start than data

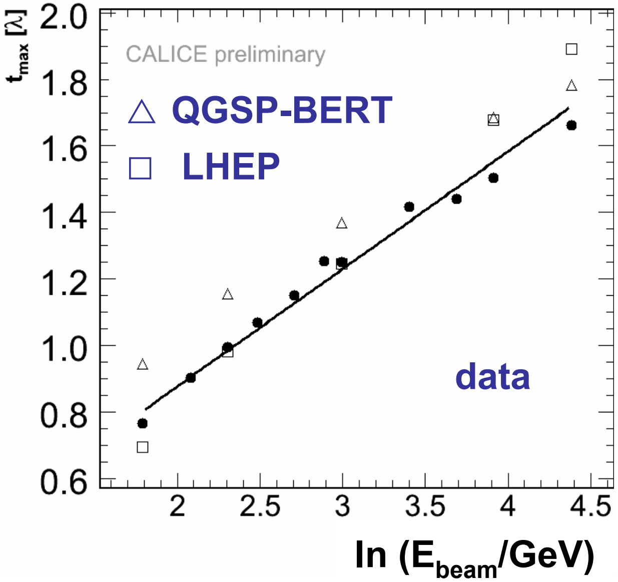
known layers with low efficiency excluded from fit

fit function:

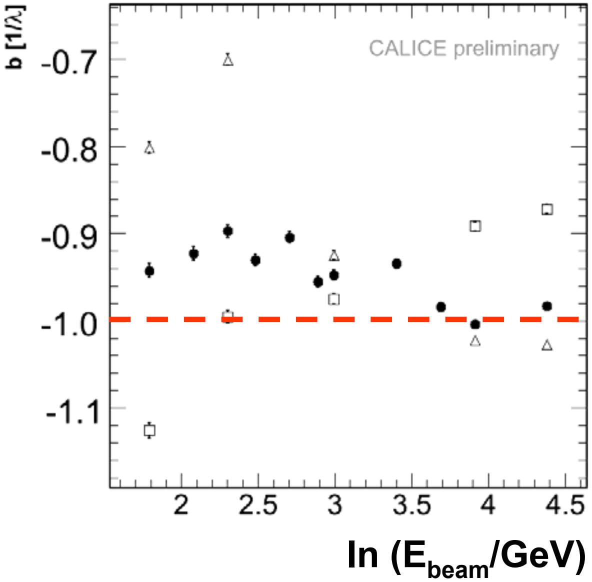
$$\frac{dE}{dt} = k \cdot t^{a-1} e^{bt}$$

b = attenuation ~ -1 λ_0

shower maximum

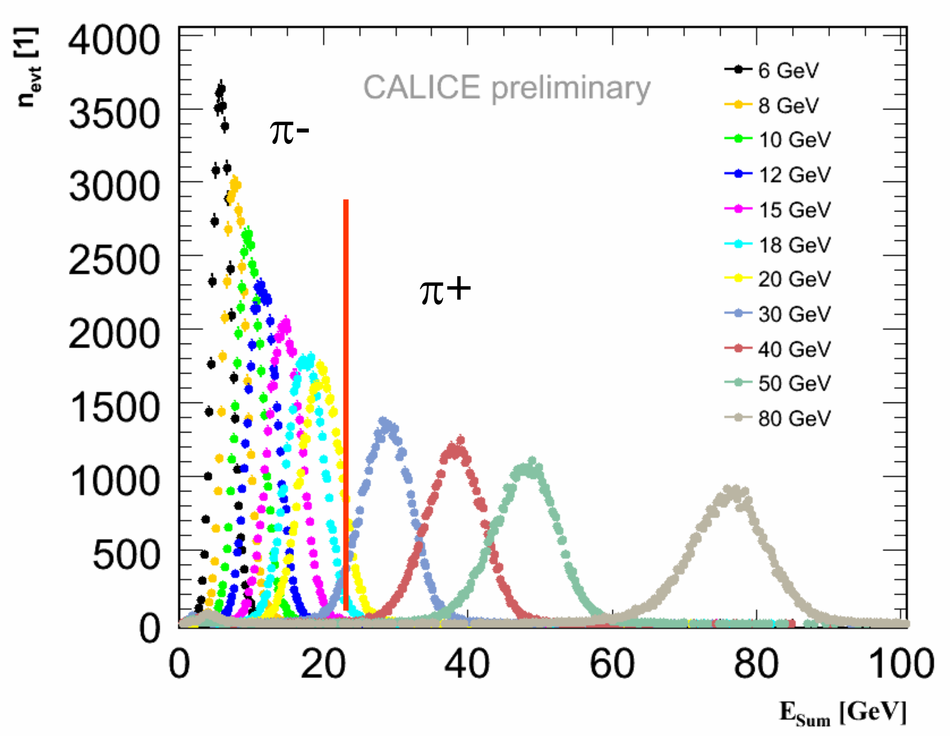


attenuation

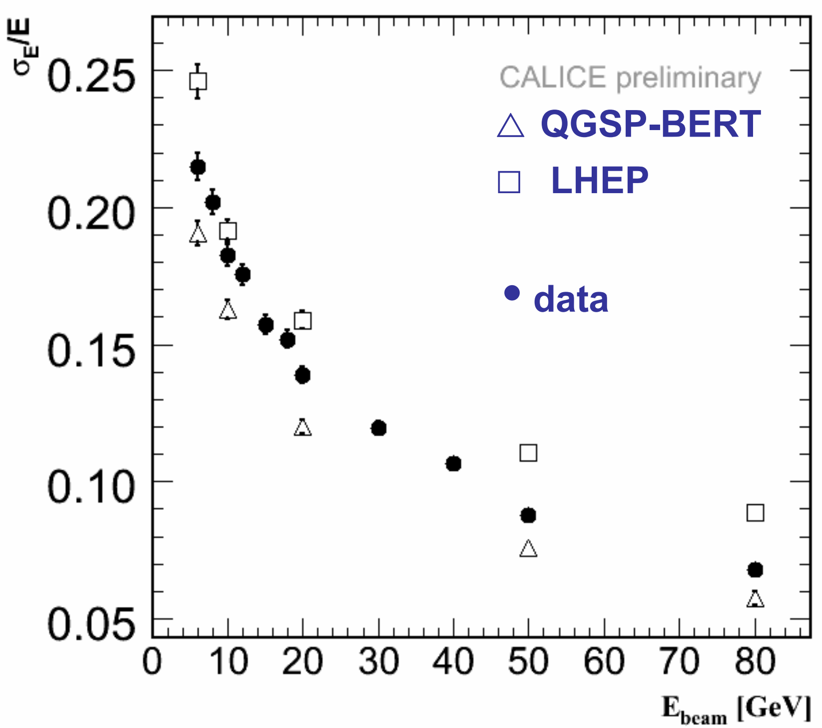


E. Garutti

Energy Resolution



contained showers in AHCAL+TCMT bias only if MC shower development in depth were different than in data

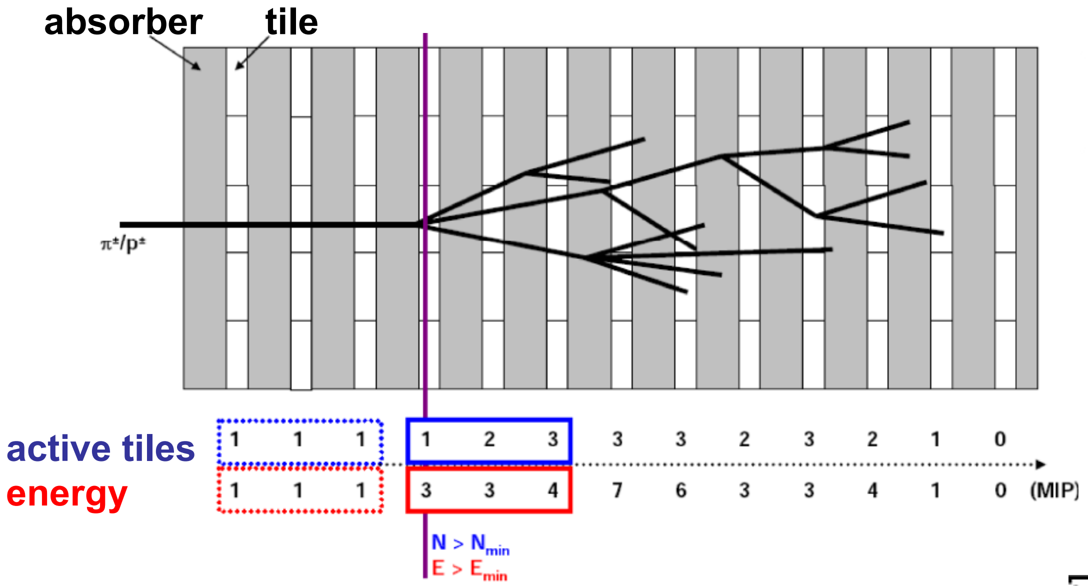


Gaussian shape of E distributions

$\sigma_E = \sigma_{Gauss}$ from fit

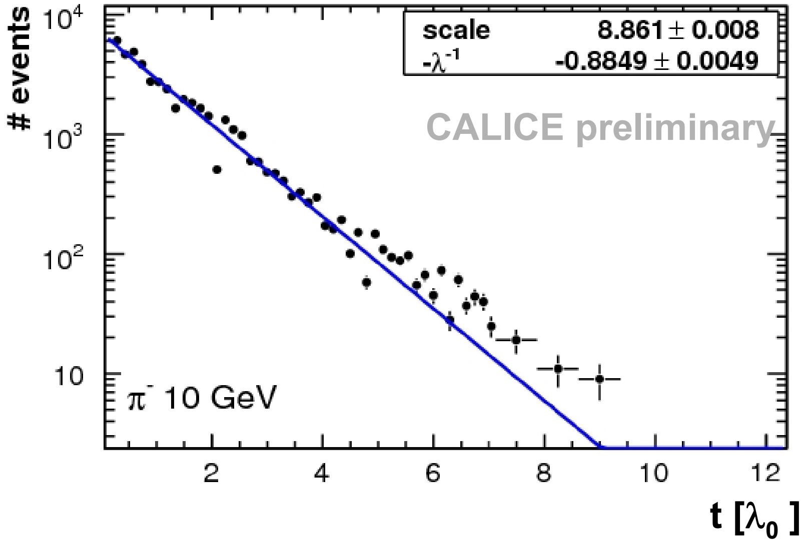
➔ no correction applied for proton contamination

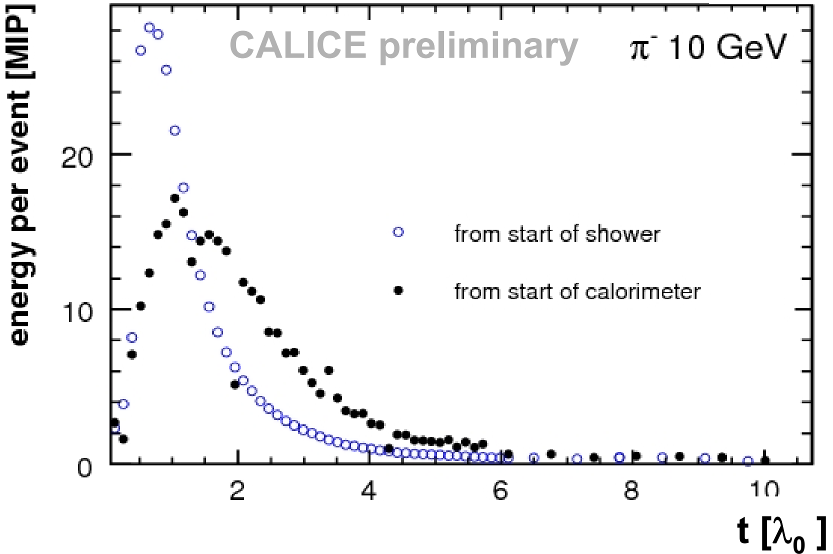
Shower starting point



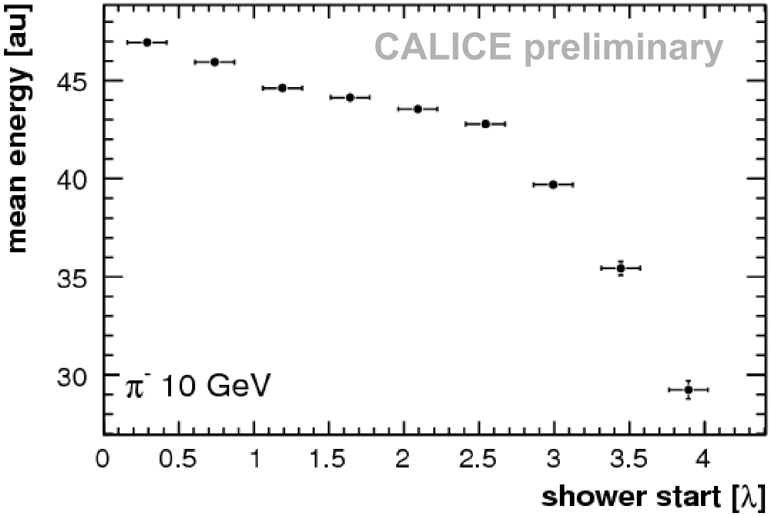
determine start of shower activities from increase of number of active tiles and energy in the 38 AHCAL layers

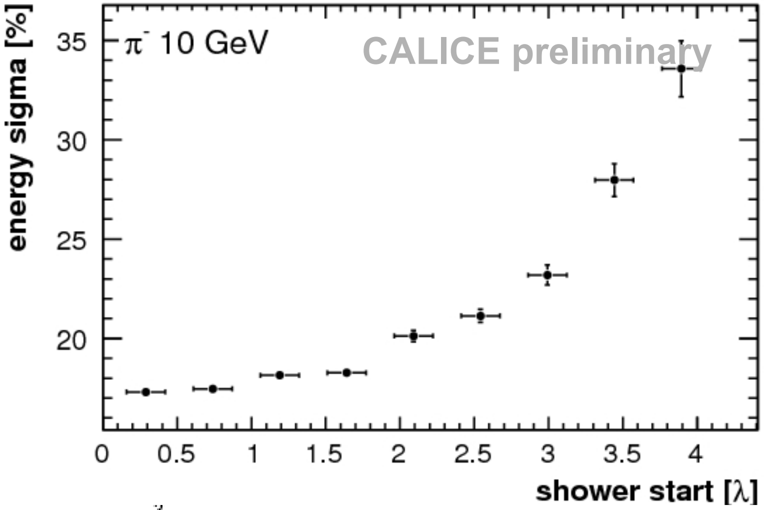
- distribution has expected exponential fall
- longitudinal shower profile after ev.-by-ev. correction allows independent data/MC comparison





Leakage correction

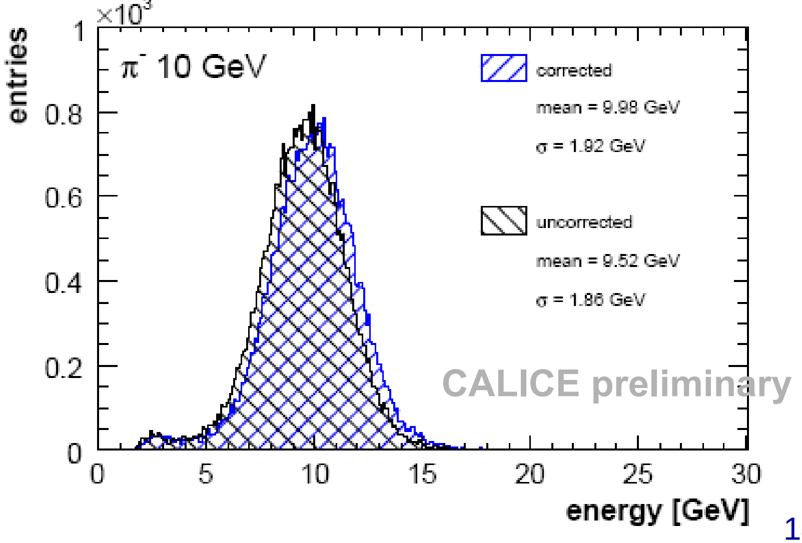




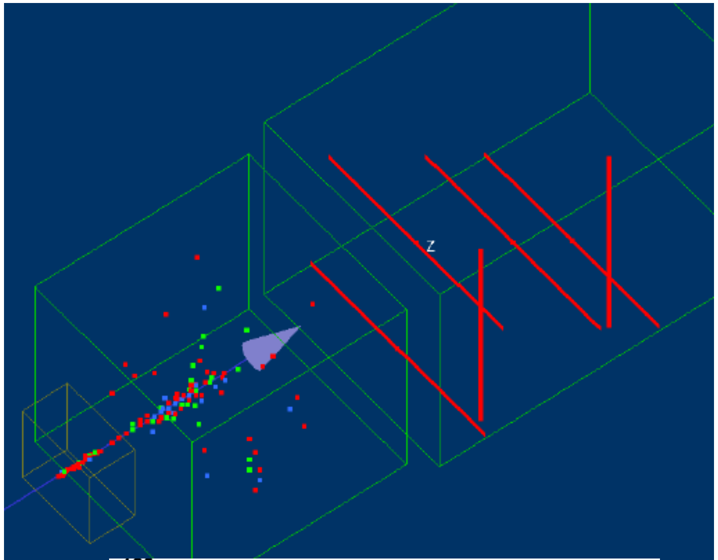
- energy contained in AHCAL decreases with depth of first interaction
- energy resolution worsens

➔ use depth-dependent correction function to re-weight the total energy

only shift in mean, no improvement
on resolution for single particle energy
but potentially useful at jet level ➔



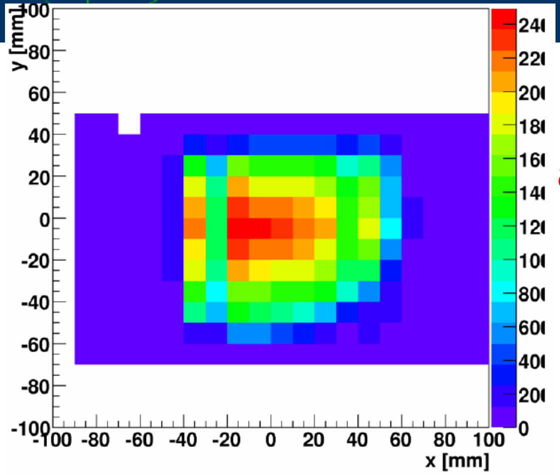
Overlay of showers



- pion sample collected at CERN SPS with CALICE calorimeters
- in the beam only single events
- but with large spread over detector front face

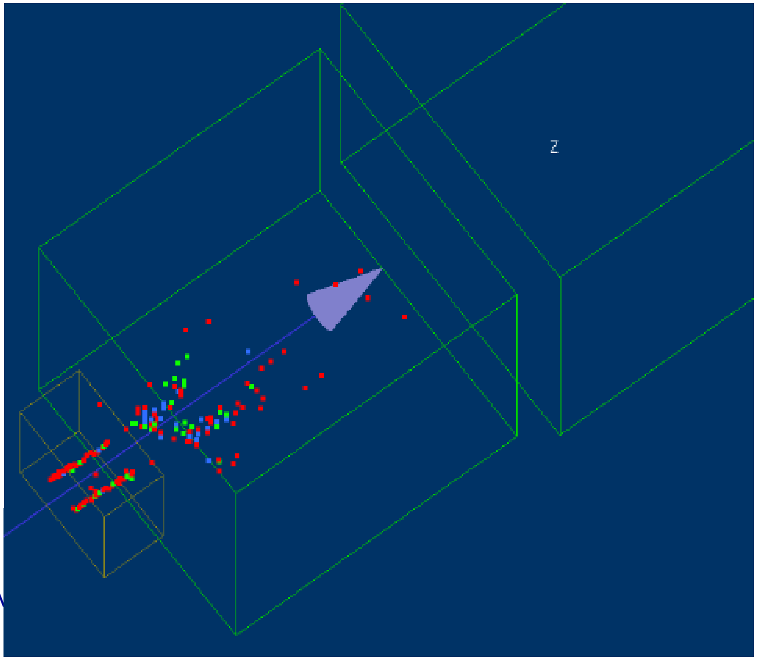
- possible to select events with given distance
- and overlay offline two showers

advantage ➔ energy of single pion is known

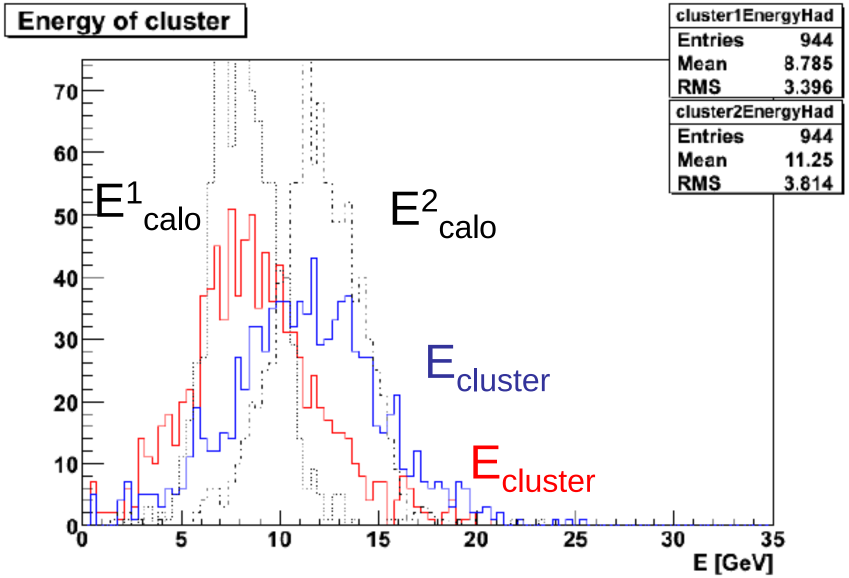


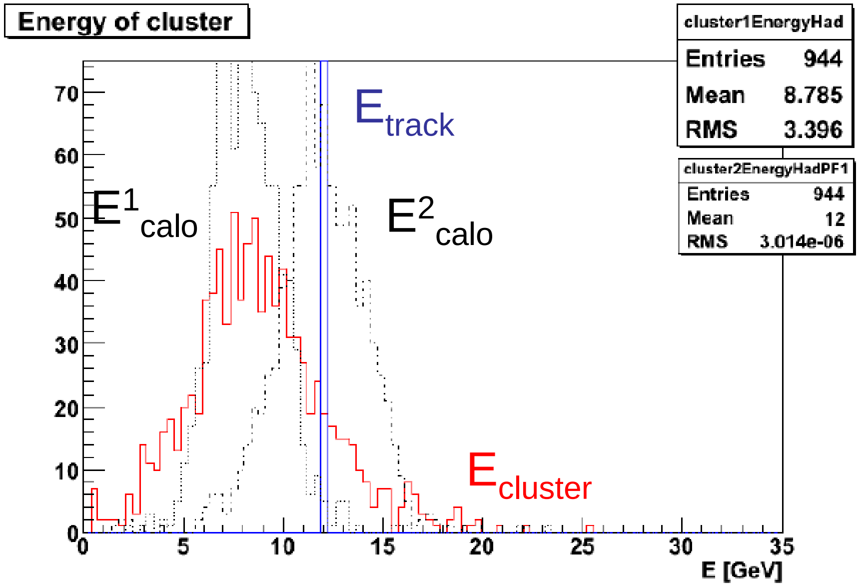
select events according to distance and overlay →

high granularity = low occupancy



Naïve particle flow



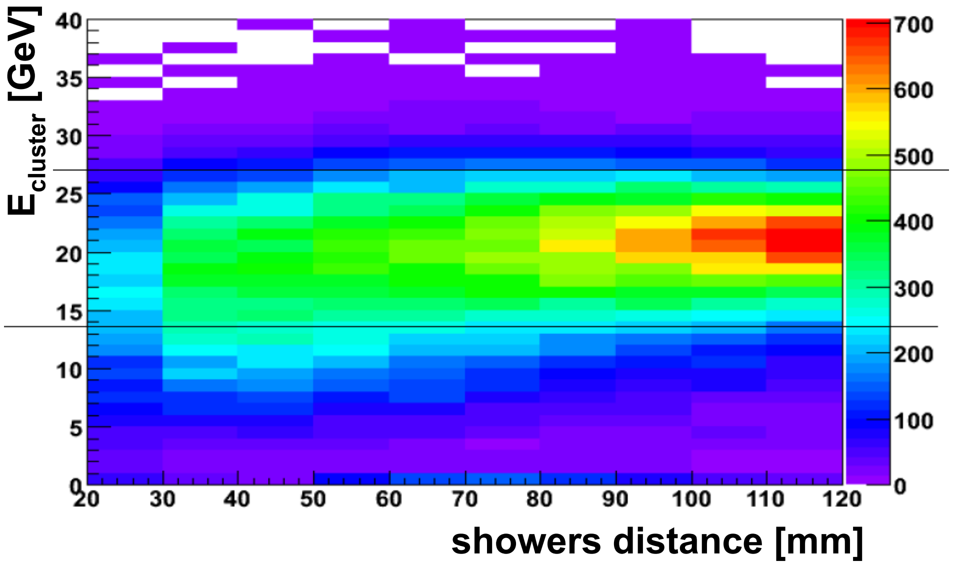


use “track-wise” clustering algorithm to reconstruct clusters, then

- assume one cluster belongs to a charge particle
- substitute energy with known momentum
- sum clusters to a Pflow reconstructed object

try to quantify shower separation efficiency (~ confusion term)

Shower separation



$+3\sigma\ E^1_{\mathrm{calo}}$

$-3\sigma\ E^1_{\mathrm{calo}}$

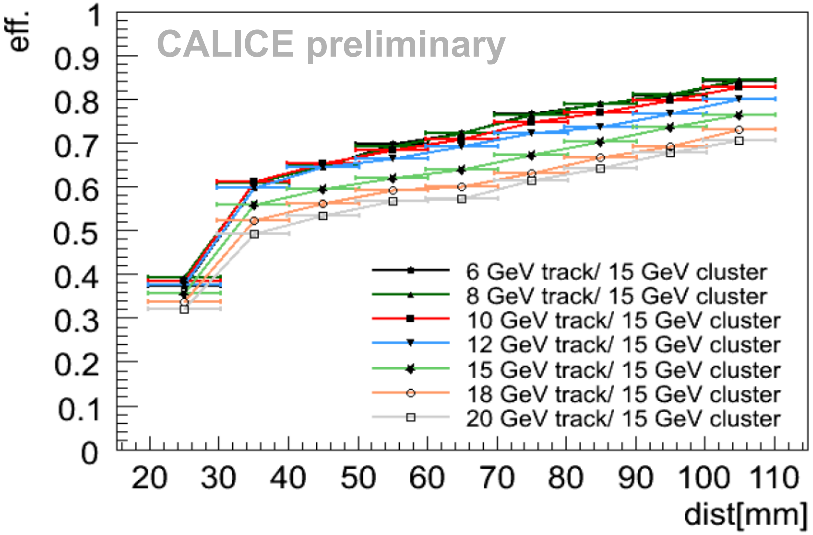
efficiency of shower separation:

$$\mathrm{eff} = \frac{\int_{-3\sigma}^{+3\sigma} E_{\mathrm{cluster}}}{\int_{-\infty}^{+\infty} E^1_{\mathrm{calo}}}$$

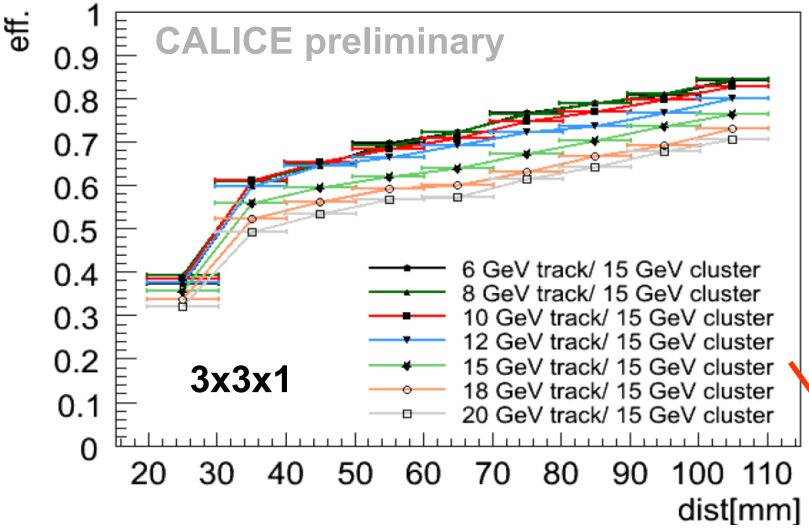
ideal Pflow: two particles at infinite distance

compare Pflow with ideal Pflow

- ➔ increasing eff. at large shower separation
- ➔ larger eff. for small track energy



Comparison to MC

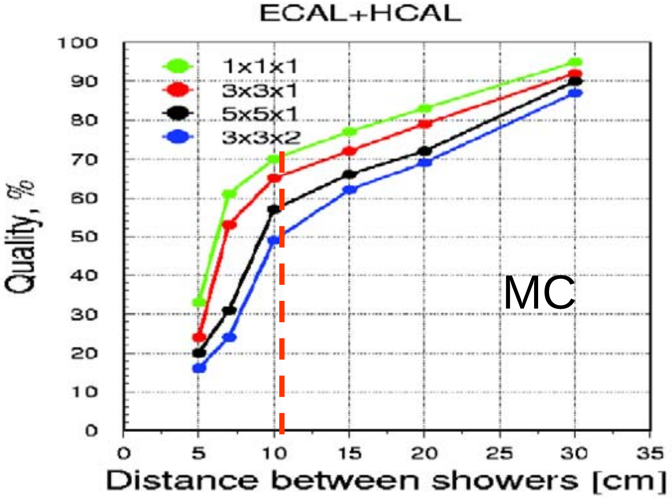


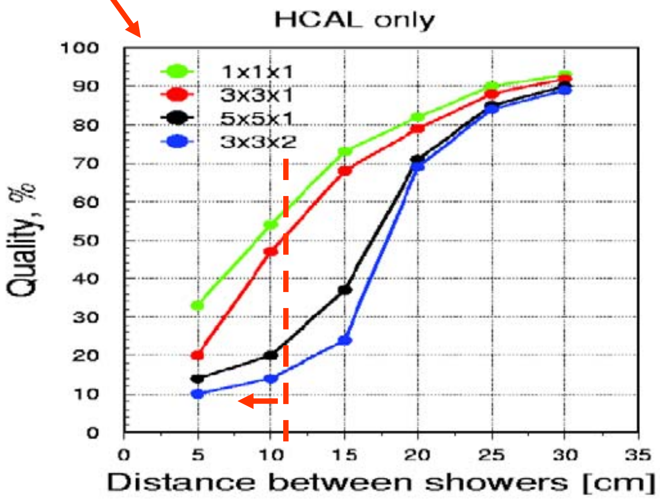
MC studies for AHCAL geometry optimization

➔ MC 1 charge + 1 neutral hadron simulated
🡐 data 2 charged pions

➔ MC with HCAL only
🡐data contained showers in AHCAL but ECAL used as tracker

qualitative good agreement





only distances <10cm probed by data

A. Raspereza, 2004

Conclusions

- The highly granular CALICE calorimeters designed for particle flow application have been successfully operated at CERN SPS – H6

the data collected are used to:

- establish the technology of analog HCAL with SIPM readout
- validate MC models
- test particle flow approach with real hadronic showers

MC digitization validated on muon and electromagnetic showers

- remaining non-linearity effects of O(5%) at E_e>40GeV
- deviations data/MC of O(10%) require more studies on detector effects

MC can be used for a first comparison to hadronic showers with O(10%) sys.

- first comparison to two hadronic models presented, more models to come
- studies of shower separation available for Pflow MC validation